Soils, Permanent Wilting Points

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INTRODUCTION

Permanent wilting point (PWP) is defined as the largest water content of a soil at which indicator plants, growing in that soil, wilt and fail to recover when placed in a humid chamber. It is often estimated by the water content at $-1.5\,\mathrm{MPa}$ soil matric potential.[1] The water content is typically expressed on a weight ($\mathrm{g\,m^{-3}}$) or volume ($\mathrm{m^3\,m^{-3}}$) basis. As the lower boundary, PWP, along with the upper boundary determined at field capacity, establishes the size of the reservoir of water held in the soil that may be withdrawn by plants, known as plant available water. Field capacity is primarily a function of soil characteristics, while PWP is the product of a combination of plant, soil, and atmosphere factors.

BACKGROUND

The soil, plant, and atmosphere act as a continuum along which soil water moves in response to gradients in energy. The energy potential of the water relative to that of pure water helps determine the amount of water stored in the soil, moved through the soil, and moved into and through the plant to the transpiring surface of the leaf. Water will flow from a region of high potential to that with low potential. The energy required to move water is expressed in terms of water potential, which is the sum of the gravitational potential, the osmotic potential, the matric potential, and the pressure potential. The matric potential is a combination of capillary and adsorptive forces due to the shape, size, and chemical nature of surfaces in the soil and plant. The osmotic potential results from the presence of dissolved substances. Pressure potential represents the solution pressure within the plant cells. For the movement of water in the soil, the pressure potential is insignificant, and the gravitational potential has little significance once it has drained to field capacity. For the movement of water through the plant, the gravitational and matric potentials are less important.

Many factors in the soil–plant–atmosphere continuum influence the amount of water a plant can extract from the soil before wilting. Soil texture affects the matric potential of the soil by determining capillary pore size and adsorptive properties, and so controls both the amount of water held in and the movement through the soil at low soil water potentials. To extract the soil water, plant roots must be distributed throughout the soil, which is a function of soil properties such as soil strength and texture as well as the rooting characteristics of the crop. Also, an osmotic potential gradient between the soil solution at the root surface and within the root must be maintained so that the water can be absorbed into the plant roots. A water potential gradient between the plant leaf and the roots helps to move water through the plant to the leaves. Water is then evaporated (or transpired) through the stomata of the leaves due to the differences in water vapor pressure between the leaf and the atmosphere. If atmospheric demand for water exceeds the water supply to the plant's evaporating surfaces (possibly due to limited soil water supply and/or movement through the soil, limited rooting by the plant, or inadequate water potential gradients between soil and leaf), the plant will experience water stress and biological activity will decline. Unless resupplied with water, the plant cells will lose pressure potential, or turgor, and the leaves will permanently wilt and ultimately die.

THE SUNFLOWER METHOD

The wide range in soil water contents at which wilting in plants occurred was noted by German researchers as early as 1859, according to Briggs and Shantz.[2] To evaluate whether plant species varied significantly in their ability to reduce the soil water content before wilting, Briggs and Shantz[2] determined the wilting coefficient for a range of soils and plant species that included native vegetation of semiarid lands as well as crop species. Veihmeyer and Hendrickson[3] and Furr and Reeve[4] continued the work of Briggs and Shantz, using sunflower (*Helianthus annuus* L.) as the indicator plant for wilting. The procedures of Furr and Reeve[4] were standardized into the sunflower method ($\mathrm{PWP_{sun}}$).[5] In this method, the plants are grown in containers of uniform soil that are sealed to limit water loss other than that by transpiration. They are kept adequately watered until the third set of leaves appears at which time the watering ceases. The plants remain in an environment with a low evaporative demand until all three sets of leaves wilt. To insure the wilting is permanent, plants are placed

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overnight in a humid, dark chamber. If all leaves remain wilted in the morning, PWP_{sun} has been reached, and the soil water content or water potential can be determined.

PRESSURE OUTFLOW APPARATUS APPROXIMATION

Permanent wilting point can be estimated as the soil water content held in the soil at -1.5 MPa matric potential ($PWP_{-1.5}$). The similarity between PWP_{sun} and $PWP_{-1.5}$ was shown by Richards and Weaver,[6] who compared the two values for 119 soils and found that $PWP_{-1.5}$ formed a fairly definite lower limit below which PWP_{sun} seldom fell. In this method, a sieved soil sample is placed on a porous ceramic plate or permeable membrane in a chamber and saturated with water. A pressure of 1.5 MPa is applied until equilibrium in water content between the plate or membrane and the soil sample is reached[5] at which time soil water content is determined.

FIELD MEASUREMENT

Ratliff et al.[7] defined field measurement of PWP (PWP_{field}) as the lowest field-measured water content of a soil after plants had stopped extracting water and were at or near premature death or became dormant as a result of water stress. Field measurement of PWP may be the most desirable method,[8] because it provides more realistic information about how a plant grows in a certain soil because the soil–plant–environment interactions are allowed to occur. But, the controls on the experiment (e.g., uniform soil in pots, low evaporative demand environment, a well-defined root zone) are gone, and the complex soil horizons, different rooting depths and patterns by crops or by the same crop from year to year, and different environmental demands can cause substantial variation. Additional problems include refilling of the profile due to rainfall, the inability to determine when plant dormancy occurs, and the drying of the upper soil layers below PWP due to soil water evaporation. In this method, the soil profile is wetted sufficiently throughout the normal rooting depth so that the plant does not undergo severe water stress until maximum vegetative growth when maximum rooting occurs. This insures that normal rooting and water use patterns develop. Water depletion patterns throughout the growing season are monitored so that the cessation of water use from a soil layer can be determined. Once plant dormancy or premature death and the cessation of water use occur, soil water content or water potential is determined.

DISCUSSION

The applicability of PWP_{sun} and $PWP_{-1.5}$ to PWP_{field} has been questioned. Ratliff et al.[7] found that $PWP_{-1.5}$ was

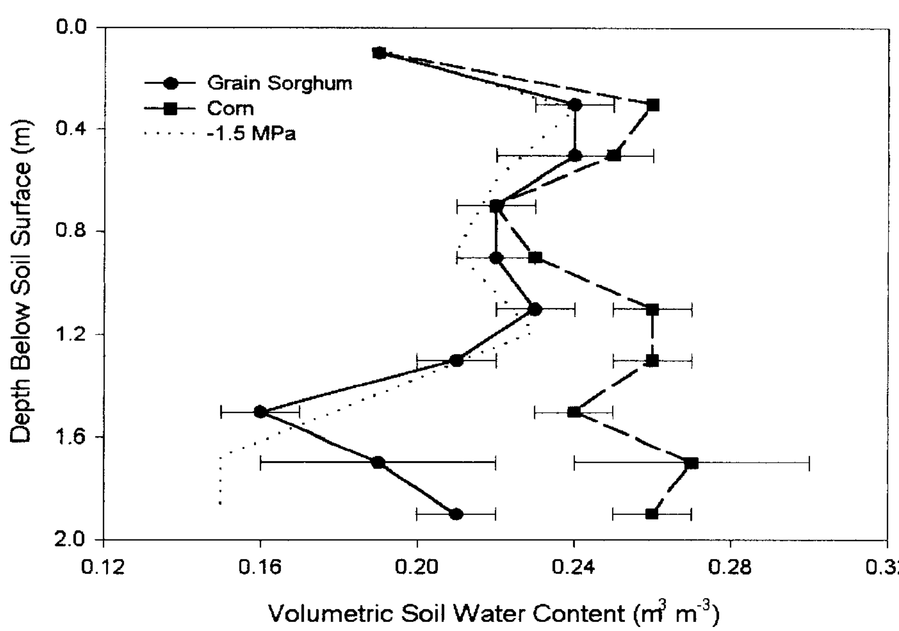

Fig. 1 Water contents of a 2-m soil profile measured for corn and grain sorghum after the available soil water had been depleted. The data points are mean values of two cropping seasons, with standard deviations (horizontal error bars). Error bars may not be visible on data points with low standard deviations. Also presented is the soil water content measured at the -1.5 MPa soil matric potential.

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significantly less than PWP_{field} for sands, silt loams, and sandy clay loams, and significantly more for loams, silty clays, and clays for a variety of crops. Additionally, PWP may be crop and climate specific. Cabelguenne and Debaeke[9] reported that corn (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench], and winter wheat (*Triticum aestivum* L.) varied in their degree and depth of lower limit of water use in a deep silty clay loam, and these capacities were representative only of the climate in which they were obtained. Savage et al.,[10] however, concluded that $PWP_{-1.5}$ corresponded to PWP_{field} for grain sorghum and cotton (*Gossypium hirsutum* L.) and values lower than measured $PWP_{-1.5}$ represented only minor amounts of available soil water.

An example of PWP for different crops is shown in Fig. 1. Grain sorghum and corn were grown in an undisturbed soil column contained in a lysimeter with a surface area of 1 m by 0.75 m and a depth of 2.3 m. The soil was a Pullman clay loam, which has a dense clay horizon about 0.4 m below the soil surface, and soil horizons containing substantial amounts of calcium carbonate beginning at about 1 m below the soil surface. The water content of the soil was measured by neutron thermalization. The vertical lines connect the means of the soil water contents for each 0.2-m depth measured at harvest for two cropping seasons for each crop, as well as the $PWP_{-1.5}$ for the different soil horizons. The horizontal lines (error bars) at each data point indicate the range in the measurements that occurred between seasons. Both crops showed a similar PWP pattern, but differed in the amount of water remaining at PWP. The dense clay horizon appears to have limited water use by both crops, probably due to restricted rooting. Grain sorghum, a more deeply rooting crop than corn, used more water from the lower soil depths. The presence of calcium carbonate in the lower depths may also have inhibited rooting. The $PWP_{-1.5}$ was similar to PWP of grain sorghum, but considerably lower for that of corn. When the volumetric soil water contents were converted to millimeters for the 2-m soil depth, the PWP for corn was 488 mm, 420 mm for grain sorghum, and the $PWP_{-1.5}$ was 398 mm. The difference between cropping seasons was 40 mm for grain sorghum, and 16 mm for corn.

Each method for the determination of PWP has advantages and disadvantages. The method selected must take into consideration the application for which it will be used, the resources available for making the measurements, and the accuracy needed.

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